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ARCTIC ACOUSTIC TRANSMISSION LOSS AND AMBIENT NOISE *

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ABSTRACT

A model is advanced to predict arctic underwater acoustic attenuation that allows some spherical and some cylindrical divergence, coupled with a reflection loss per unit distance. Data collected from a variety of sources of measurements of arctic transmission losses are used to derive reflection loss and to compare with the model. The standard deviation of error between measurements and model is found to be ± 5 db at the lowest and ± 6 at the highest frequency of measurement. The effects on transmission loss of such factors as source, receiver and bottom depths are discussed. The results of a year-long measurement program at Ice Island T-3 to study arctic ambient noise are given.

ARCTIC ACOUSTIC TRANSMISSION LOSS AND AMBIENT NOISE

In every field of applied science there exist practical limits imposed by the real world that restrict experiments and otherwise hamper efforts to substantiate theoretical work. Researchers are continuously striving to find ways to hold constant some unknown variable, reduce interferences or otherwise lower "noise" to make their measurements. This truism applies of course to all fields of science but always seems to pertain especially to one's own work – in this case the oceanographic science of underwater acoustics.

Based on preliminary measurements made a few years ago, the Arctic Ocean appeared to offer a unique opportunity for the conduct of acoustic experiments that were not feasible in any other ocean. Where the upper layers of the open oceans of the world are temporally and spacially non-stationary, the Arctic Ocean's temperature and salinity and hence sound velocity profiles are almost constant. Therefore, sound propagation in the arctic should be predictably constant, or reasonably so. Where that part of the open ocean that is stationary and provides efficient sound propagation is very deep and almost inaccessable to our current technology, the sound channel axis in the arctic is at the surface. Where in the open ocean acoustic instrumentation is hung, strung, dangled, dragged and towed from expensive platforms (ships), and attended by seasick scientists, in the arctic it is necessary only to drill a small hole in the stable platform afforded by the ice itself and lower a hydrophone a hundred feet or so. Where in the open oceans ship traffic is an almost constant source of noise, it is almost non existent in the Arctic Ocean. Because of these and other factors, we envisioned that in the arctic we would have the opportunity to build and test very large-aperture hydrophone arrays at a small fraction of the cost of trying the same in open water. Advanced processing techniques could be tested on these arrays years in advance of anything comparable in the open ocean.

This is not to say that there was no interest in the Arctic Ocean per se. On the contrary, from the time in 1958 when U.S.S. NAUTILUS traversed this ocean completely submerged and proved it to be just another ocean to the nuclear submarine, the arctic assumed strategic importance as an operating ocean. From our early measurements during the IGY we knew it to be a highly unique ocean with entirely different environmental and oceanographic characteristics that affected the acoustics.

The basic parameters of the transmitting medium that affect sonar design are transmission loss and ambient noise. The first and foremost task of the arctic acoustics research program was the measurement of these parameters. This task was preliminary to both a basic understanding of the ocean and to the long-range idea of using the arctic as a test-bed for acoustic instrumentation.

Transmission Loss

Over the years 1958 thru 1962, U.S. Navy Underwater Sound Laboratory was the most active single organization in measuring arctic transmission loss. Its work during that period included measurements between the drifting stations T-3, Alpha, Charlie, Arlis II, and Polar Pack I, and between these stations and the U.S.S. STATEN ISLAND. P2V aircraft also were used to gather loss data. The results of this measurement program were recently published by Mellen and Marsh[1] who reported a compendium of transmission loss measurements analyzed at discrete frequencies from 20 to 6400 Hz.

Since 1962 GM Defense Research Laboratories (GM DRL) has made similar but not so extensive measurements that span approximately the same ranges as those of USL. We made these measurements between T3 and ARLIS III and ARLIS IV and from our temporary drifting stations in the Beaufort Sea, using ARL light aircraft to launch explosive charges. For all of this work a standard navy Mk 61 (2 lbs TNT) Sound Source set for a 250-meter detonation depth was used. Some of these latter measurements were reported by Buck and Greene[2] in 1964.

Empirically, through a large number of measurements of transmission loss made in the open ocean, NRL found that for the case of a half-sound channel bounded at the surface (i.e., the same situation presented by the stable positive sound velocity profile in the arctic) the divergence loss (N_d) can be approximated by:

$$N_d = 20 \log \frac{r_o}{4} + 10 \log \frac{R}{r_o/4} = 10 \log r_o + 10 \log R - 6 \qquad (1)$$

where r_o is the skip distance of the deepest travelling ray and R is the range.

Equation (1) represents spherical spreading to one-quarter of the distance that the deepest limiting ray travels from the source to where it strikes the surface, and then cylindrical spreading thereafter.

In the Arctic the only other significant loss at low acoustic frequencies, where absorption can be neglected, is the loss suffered at each ray reflection at the water-ice interface. For long-range propagation where many reflections occur, this reflection loss can most simply be handled as a loss-per-unit distance. This loss will of course be a function of frequency, since the degree of "roughness" of the ice reflecting surface, hence its scattering power, is a matter of wavelength of the impinging sound. Therefore the total transmission loss (N_W) is represented by:

Total loss = divergence loss + reflection loss

$$\begin{aligned} N_w &= N_d + N_r \\ &= 10 \log r_o + 10 \log R - 6 + N_r' R \qquad (2) \end{aligned}$$

where N_r' is the reflection loss per unit distance.

The USL and GM DRL loss data were combined (along with a very limited amount of constant-wave source data collected at 1030 Hz by Naval Electronics Laboratory in the summer of 1952 – the only known medium-range data taken with other than explosive sources) and an effort was made to best-fit these with single smooth curves at discrete frequencies. To accomplish this, the value of reflection loss per unit distance (N_r') for each frequency was found such that Equation (2) above best fitted the actual measurements. The resulting curves are shown in Figure 1. Also shown are the standard deviations of the actual measurements from the curves. There was a considerable spread in measured values of loss at almost all ranges (as much as 30 db). The main reasons for this spread are believed to be: unknown variations in yield of a large portion of the explosive signals; reflection effects at the source and hydrophone receiver which were not accounted for; different bottom depths; and a certain amount of measurement error. The following discussion will explain the considerable effect on transmission loss of source, receiver and bottom depth.

Since at the lower frequencies the wave lengths are comparable to the source and receiver depths of the loss measurements made in the arctic, the Lloyd Mirror Effect must be considered in evaluating the efficacy of the data. Figure 2 is a representation of this effect on transmission loss derived from the simple geometry of the arriving waves. Note, for example, that at the average hydrophone depth used in the experiments (60 meters) there is an amplification of the signal of about 6 db at 40 Hz. This amplification quickly becomes a loss as the receiver is moved toward the surface. The same holds true of the explosive source depth. Again, using 40 Hz as an example, we see that a source at 60 meters effectively gains 6 db in source level because of reflection near the source that enhances the shallow-travelling rays that propagate to great distances. The curves in Figure 2 are idealized. In practice it has been found that they represent observed results from the first minimum near the surface to the first maximum (or 6 db enhancement point) for any given frequency but below that there is considerable variation from the theoretical.

Figure 3 further exemplifies the need for control of source depth in transmission loss measurements. The two recorder traces are for identical 2-lb TNT (Mk 61 Sound Sources) charges set off at T-3 and recorded with a 30-meterdeep hydrophone at ARLIS IV, then 330 nautical miles away. The top trace is for a 245-meter, and the bottom, an 18-meter explosion depth. All other conditions are identical; however, note the greatly increased bottom bounce arrivals for the shallow shot. These arrivals comprise more than half the total arriving energy, the rest being in the water-travelling rays. For the deep shot, the bottom bounce energy is a very small fraction of the total energy. The reason for this is that, for the shallow shot, reflections close to the source enhance the ray emenations that depart at the greater angles and which propagate as bottom-bounce rays. For the deep shot the geometry is such that the small-angle, shallower-travelling rays that do not strike bottom are enhanced and the deeper travelling rays are not. Aside from its affect on propagation, source depth is also important in determining the actual spectral content of the explosion.[3]

Bottom depth along the path plays an equally important role in determining transmission loss. Figure 4 illustrates this point. Here is shown a typical explosive

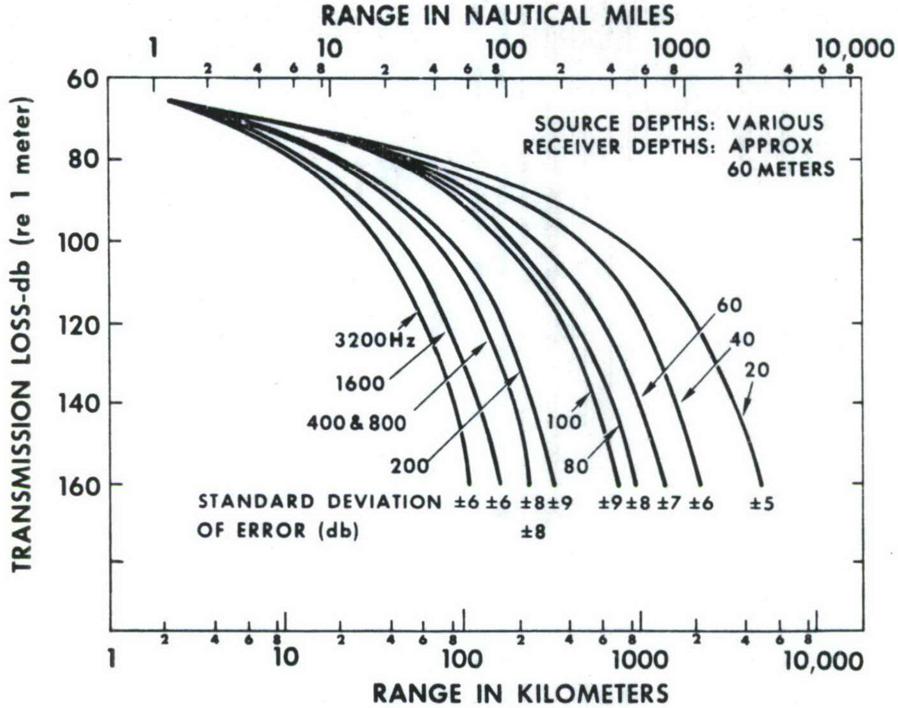

Figure 1 Best-Fit to Transmission Loss Measurements in Arctic Ocean

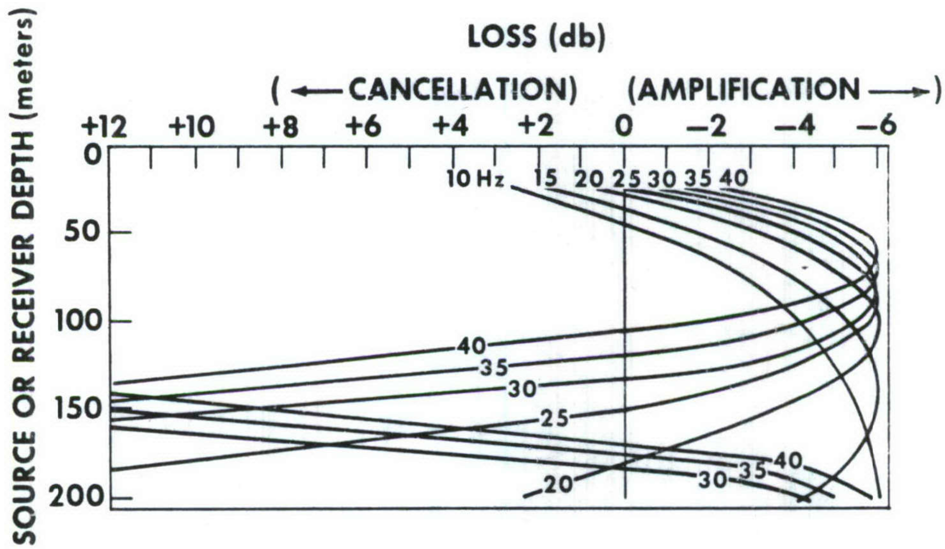

Figure 2 Effect of Surface Reflection Near the Source or the Receiver on Signal

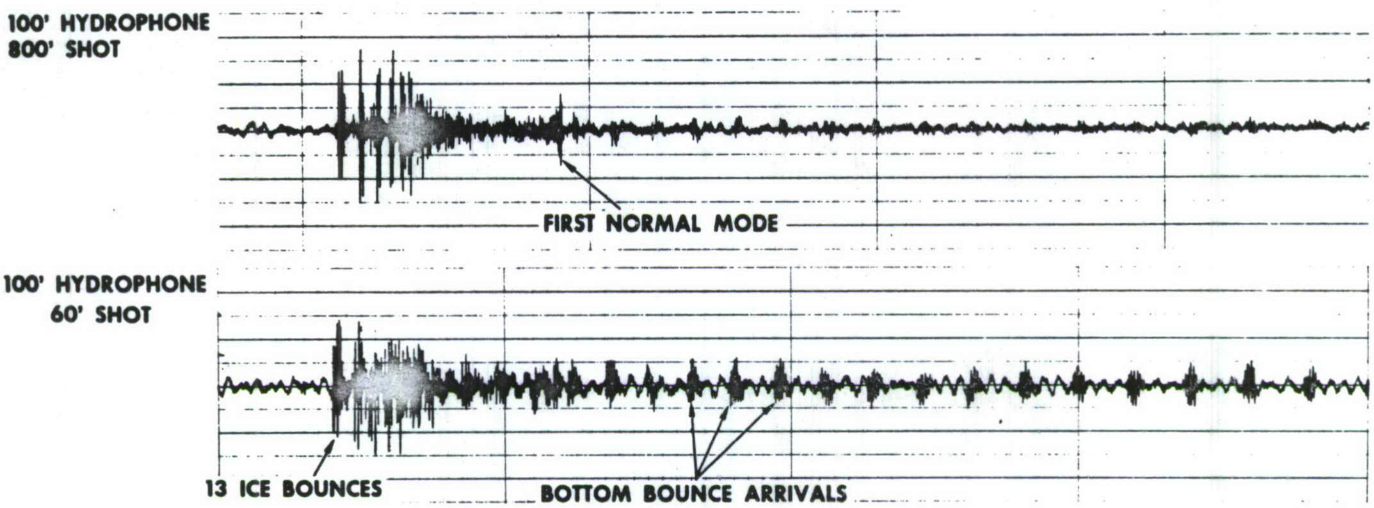

Figure 3 Effects of Source Depth on Arriving Signal Energy

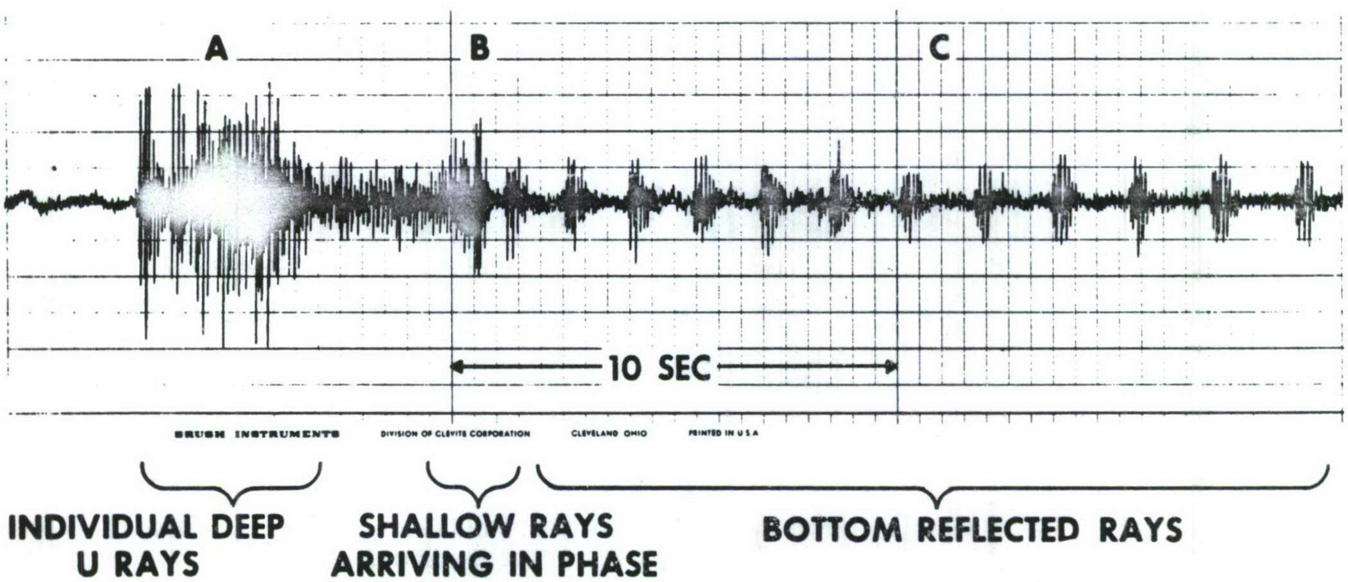

Figure 4 Typical Explosive Source Signal Arriving from Long Distance over a Deep-Water Path

signal arrival over a deepwater path. The first energy to arrive (Group A) is from deep-travelling rays that arrive as individual energy packets. The next group (B) is comprised of shallow-travelling rays that arrive in phase addition, giving what is sometimes called the "first normal mode" arrival. The last group (C) are the bottom bounce rays that arrive at ever increasing intervals. Now, if there is water shallower than about 500 meters along the transmission path, ray theory predicts that the Group A arrivals will not be present. This represents a considerable reduction in total signal strength. If the bottom is deep but the source depth is below about 500 meters there will be an A and C group but no B since those rays propagate shallower than 500 meters. For a source below 500 meters and with water shallower than 500 meters anywhere along the path, both Groups A and B will be absent, leaving only Group C. Any of these conditions greatly affect the total energy in the arriving signal. The above discussion explains the great variability in the transmission loss measurements made to date in the arctic since these measurements were made without any of the various factors held constant. Therefore, the curves of Figure 1 are but gross generalizations of the loss to be expected under any given set of conditions of source, receiver, and bottom depths. A much more extensive program is needed before measurements can be related to theory or valid prediction can be made based on empirical results. In the meantime, however, we can make a "best estimate" of transmission loss, using the curves of Figure 1 or Equation (2), with values of deepest-ray skip distance (r_o) and reflection loss per unit distance (N_r') as given in Figures 5 and 6, respectively. (We derived these latter curves by using ray theory based on the stable, well known sound-velocity structure of the Arctic Ocean.)

Ambient Noise

Early measurements of ambient noise from drifting ice stations in the arctic were greatly hampered by cable flutter (or "strumming") noise problems. During periods of high wind and rapid ice movement, when the ambient noise could be expected to be the highest, measurements could not be taken because of measurement-equipment saturations caused by this cable flutter. The result was that measurements were taken only during periods of relative calm and this lead to an eroneous conclusion by many that the arctic was acoustically quieter than it actually was.

GM DRL undertook in 1965 a continuous program (three-times daily) of measurements to determine the statistical qualities of the levels of ambient noise in the band 18.75 to 1200 Hz. We used a 30-meter hydrophone with a special plastic cable fairing and placed it one-half mile remote from the camp at T-3. As of April 1966 this program has been in effect for one year.

Figure 7 is a composite of all readings made of the period April 1965 to March 1966. It gives the median, 99 and 1 percentiles of recorded sound spectrum levels versus frequency in the band of measurement. Also shown for comparison is Knudsen's ambient noise curve for sea state zero in the open ocean.[4] (It must

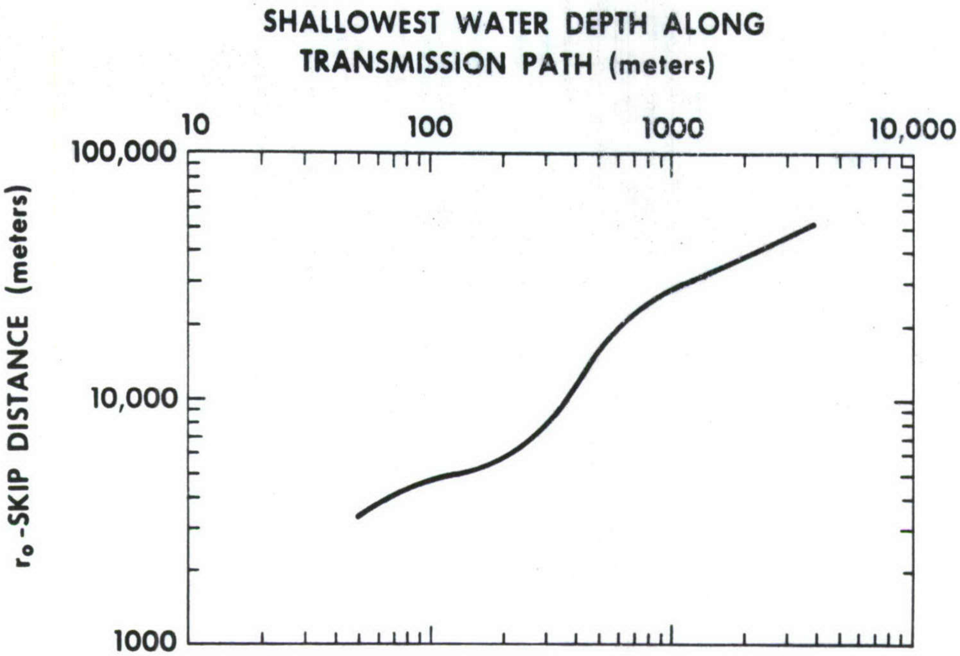

Figure 5 Skip Distance of Deepest Propagating Ray

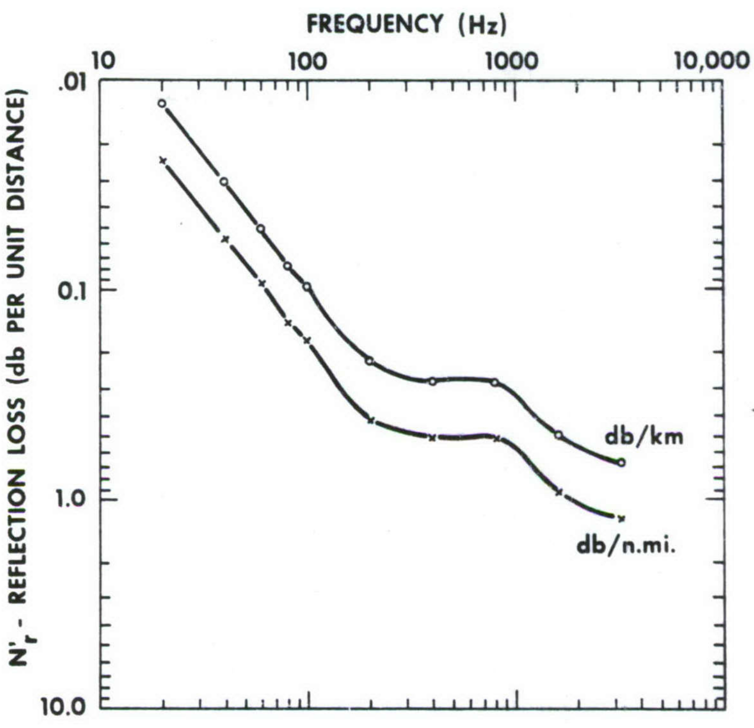

Figure 6 Reflection Loss Versus Frequency

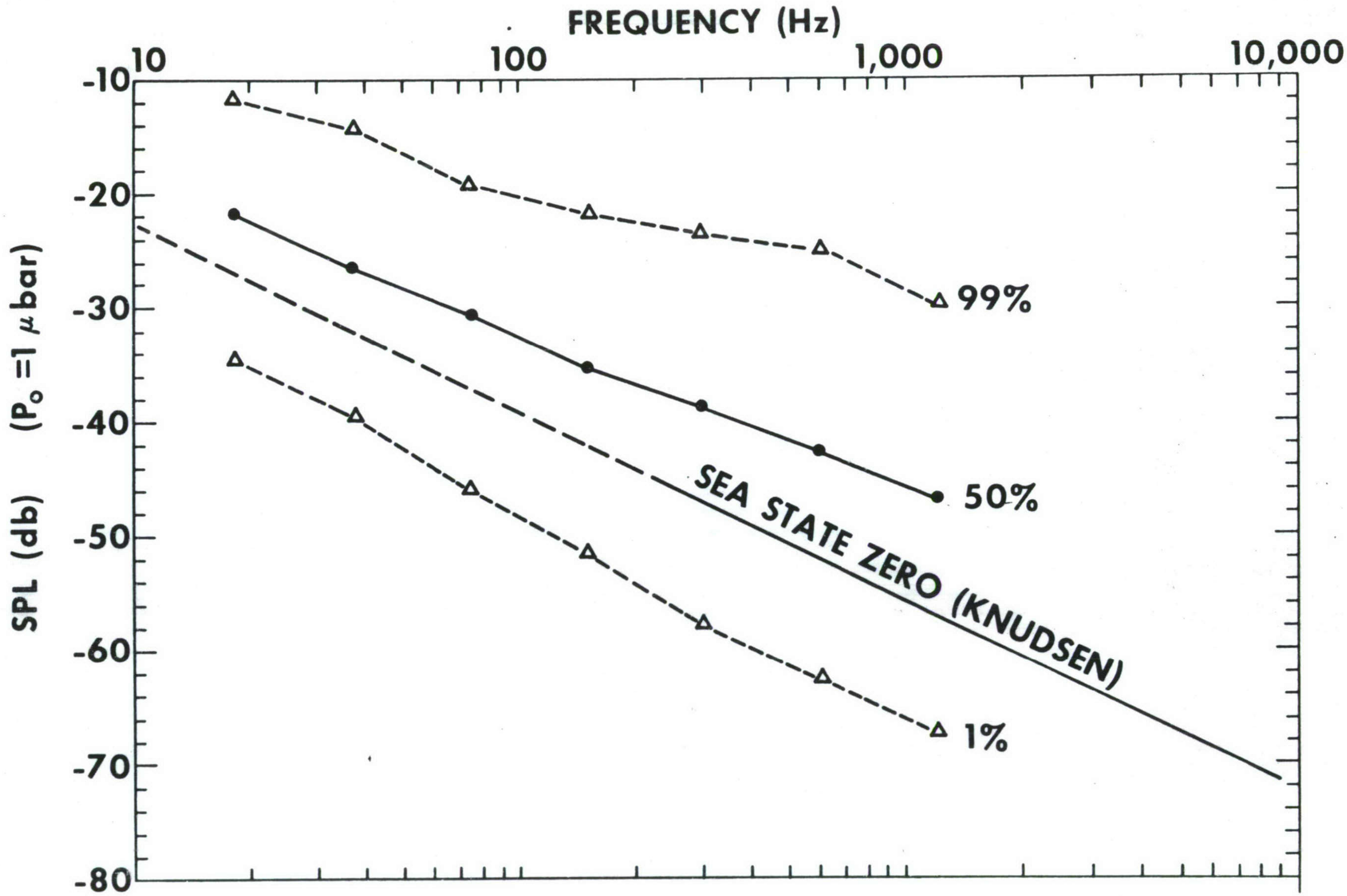

Figure 7 Median, 99, and 1 Percentiles of Sound-Pressure Level of Ambient Noise for Period April 1965 through February 1966

be emphasized that below a few hundred cycles the Knudsen curves are not truly representative of the open ocean. At these low frequencies the ambient levels are greatly dependent upon local ship traffic conditions. In traffic-free areas the levels are much less than those depicted by the Knudsen curves below about 200 Hz.)

Although there certainly can be contributions from biological sources, the background noise in deep arctic water is attributed largely to ice activity. At the low end of the frequency spectrum the background is, in all probability, due primarily to gross ice movement (of the type observed in pressure ridging) that originates from nearby out to extreme distances. In the mid-frequency range, local ice-fissure generation and distant gross ice movement probably contribute about equally to the noise. Milne[5] has found that the high frequencies are dominated by local ice cracks which are caused by thermal changes during periods of low wind, and by wind turbulence at the air-ice interface during periods of high wind.

The presumption that low frequency noise is more dependent on remote ice activity than is high frequency noise is borne out by the transmission loss curves shown in Figure 1 and the correlation diagrams of Figure 8. In the latter figure, 10 months of median spectrum level data have been plotted for each frequency versus the corresponding median spectrum level data at 1200 Hz. There is an evident systematic decrease in the degree of correlation at lower frequency, suggesting that the lower frequencies are more affected by distant ice movement. There is a certain amount of correlation, however, indicating that both the low and the high ends of the band of measurement are influenced by nearby ice activity, as might be intuitively predicted.

Since pack movement and therefore pressure ridging can be to some extent correlated with local wind, we might also expect a correlation between the levels of low frequency ambient noise and local wind. Figure 9 shows the result of correlating these two quantities. Note that there is indeed a certain amount of correlation, and at most frequencies investigated the maximum was at a correlation time of zero. There is a negative correlation maximum at about 64 hours before and after a correlation time of zero. Also shown in Figure 9 is an auto-correlation of local wind force. It indicates a period of about 120 hours, which is close to the periodicity of the ambient noise. At 300 and 600 Hz there are indications of a correlation positive maxima 8 to 16 hours after time zero. This is considered more evidence of the greater relative dependency of the higher frequencies than of the lower frequencies on local ice activity. The reasoning behind this is that local ice movement must, on the average, lag local high wind conditions. These correlograms represent only a small section of our data and should be considered preliminary. A much more extensive analysis of wind effects will be accomplished in the future.

In Figure 10 the median levels of noise at 18.75, 150 and 1200 Hz and the median temperature and median wind speed for each month have been plotted to indicate the seasonal variation. Again it is seen that there are no strong correlations

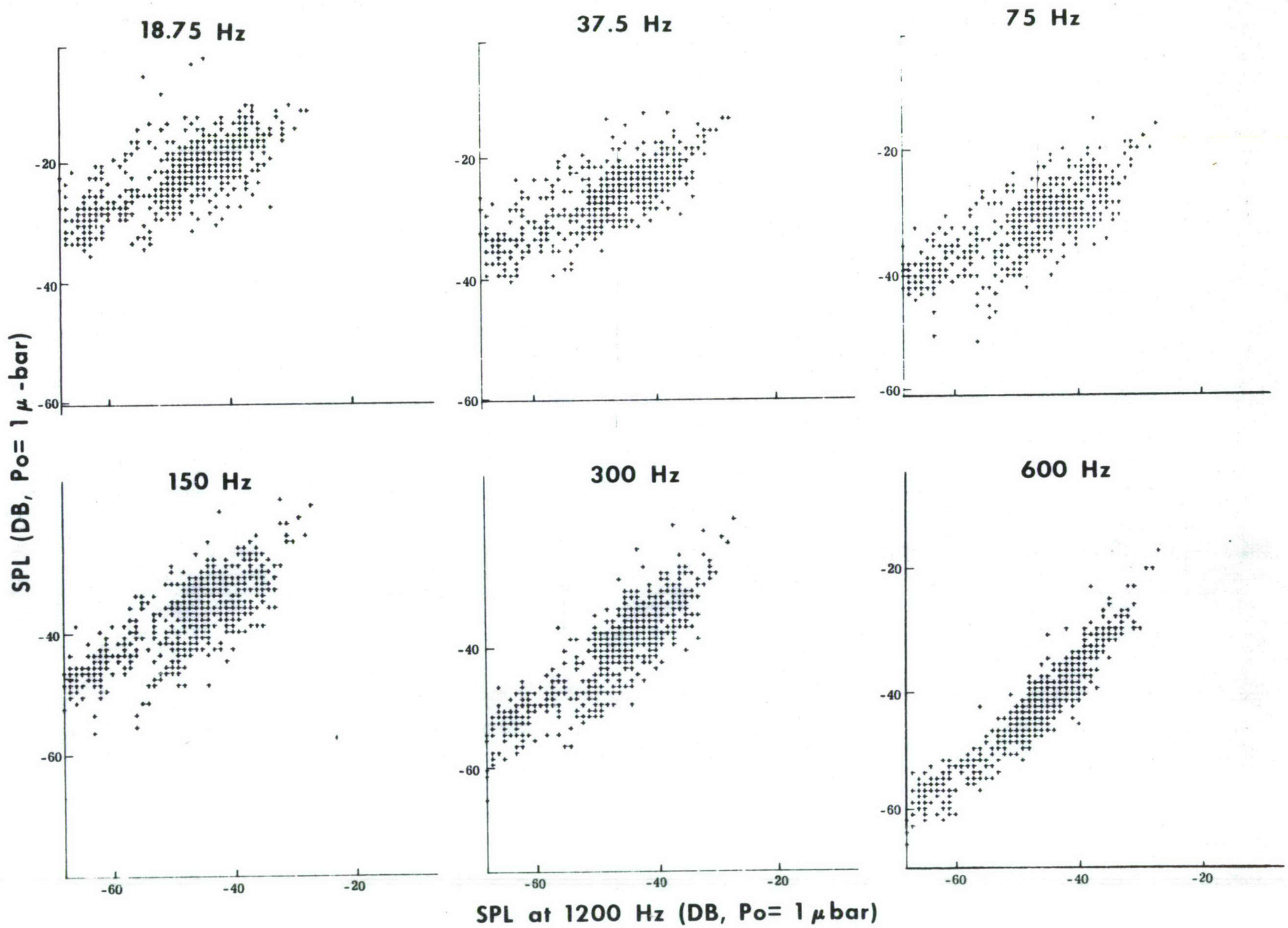

Figure 8 Correlation between Median Levels at Different Frequencies and Corresponding Median-Spectrum Levels at 1200 Hz

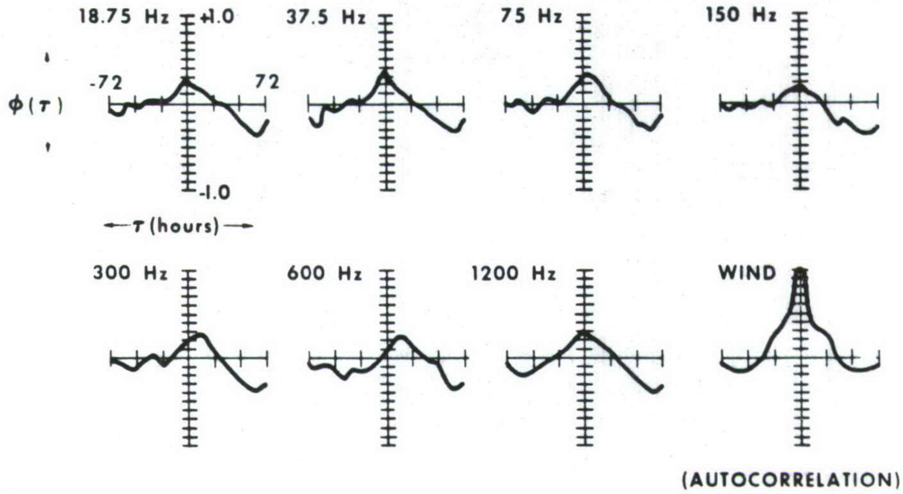

Figure 9 Cross Correlation between Ambient Noise and Wind Speed for the Month of June 1965

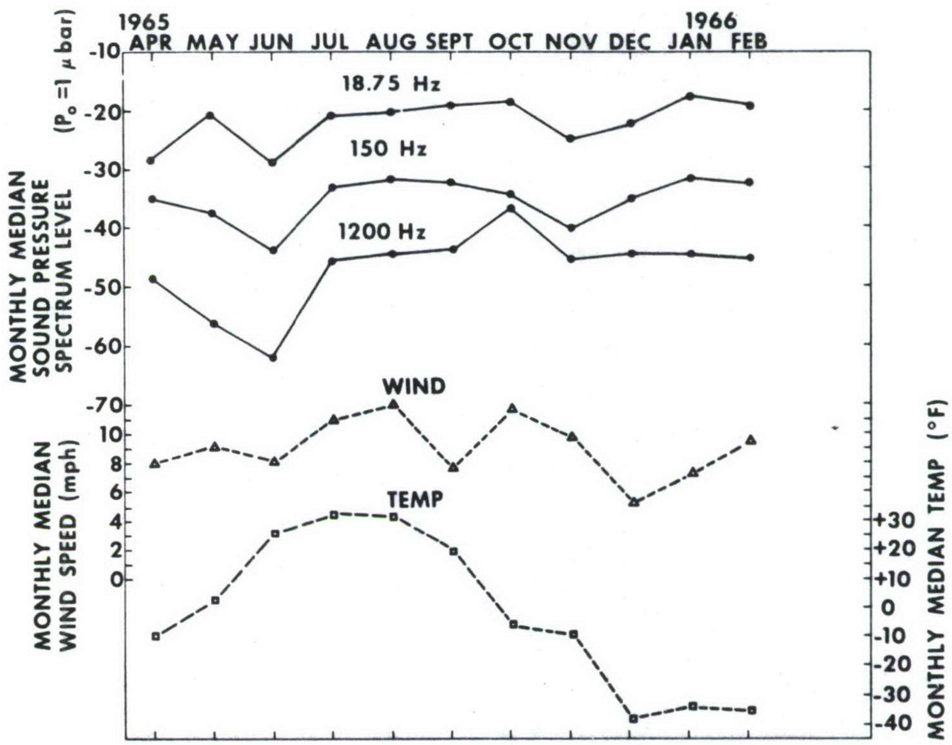

Figure 10 Seasonal Variations of Monthly Median Values of Noise Levels, Wind Speed, and Temperature

between noise levels and wind or temperature, nor is there any apparent seasonal dependency. There is, however, considerable variation of median noise levels from month to month. A second year of measurements will indicate if this variation is truly as random and independent of seasons as is implied in Figure 10.

Measurements were also made of the strength of ambient noise as a function of hydrophone depth. For this test two hydrophones were used. One remained at a depth of 91 meters while the second was raised in steps of 6 meters. The fixed hydrophone served to detect any significant changes in the level of the noise while the second was being raised. We found that the noise level at all frequencies investigated remained essentially constant (plus or minus about 2 db) for depths below that equal to approximately one-half wavelength (see Figure 11). The levels dropped sharply at shallower depths. Referring again to Figure 2 we see that the first maximum for a 6 db signal enhancement due to the Lloyd Mirror Effect (LME) is at a depth greater than a wavelength for all frequencies. This implies that a hydrophone depth equal to that corresponding to the LME first maximum gives an optimum signal-to-noise ratio at all frequencies investigated. For a velocity sensor such as a seismometer, the optimum location is at the surface. However, simultaneous measurements (see Figure 8 of Reference 2) indicate that for frequencies greater than about 10 Hz the signal to (average) noise ratio for a 60-meter deep hydrophone is greater than for a seismometer imbedded in pack ice. Table I, below, indicates the degree of this superiority:

Table I

HYDROPHONE/SEISMOMETER $S/\overline{N}$ COMPARISON

Freq (Hz)		$S/\overline{N}$ (hydrophone minus $S/\overline{N}$ (seismometer)(db)
25	.....	8
100	.....	10
500	.....	20
1000	.....	20

Conclusions and Recommendations

There still remains considerable experimental work to be done in the arctic before reliable predictions of transmissic loss and ambient noise can be made. This work should include measurements acquired through use of explosive sources and high-power CW projectors under carefully controlled conditions of source, receiver and bottom depths. The theoretically predicted effects of reflections near the source and receiver should be verified experimentally. Longer-term measurements should be made of ambient noise levels over a frequency range extended beyond that of previous measurements. The anisotropy of the ambient noise field should be investigated. There is also a need for continuous measurements of noise to determine periodicity and for measurements at different geographical locations.

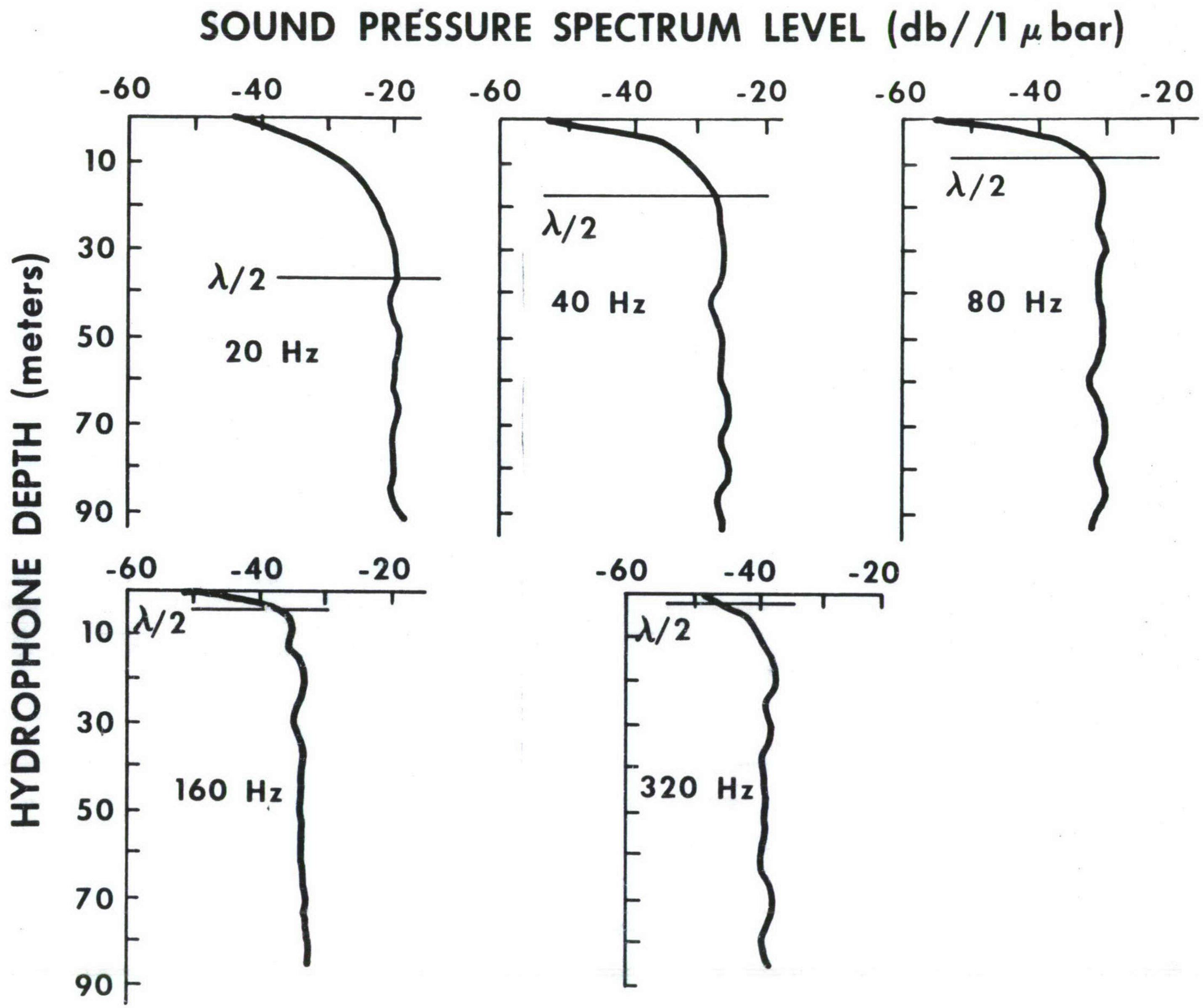

Figure 11 Ambient Noise as a Function of Hydrophone Depth at Selected Frequencies

Drifting ice stations will continue to play an important role in acoustic measurements and some consideration must be made to the matter of improving these stations as acoustic platforms. For example, there is a definite need for acoustically quiet electrical power supplies for the stations and for the close cooperation and understanding of other investigators in maintaining a quiet camp so that effective acoustic measurements can be made on a continuous basis.

When the above conditions have been met we will have gone a long way toward the day when the arctic can be used as a highly effective test-bed for advanced acoustic system research and development.

Acknowledgement

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13. ABSTRACT

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